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THE SIMULATION AND CONTROL OF A GRID- CONNECTED WIND ENERGY CONVERSION SYSTEM

by

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B.S. University of Central Florida, 2008

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science of Electrical Engineering
in the Department of Electrical Engineering and Computer Science
in the College of Engineering and Computer Science
at the University of Central Florida
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Major Professor: Jiann S.Yuan

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ABSTRACT

With the rising cost of petroleum, concerns about exhausting the fossil fuels we depend on for energy, and the subsequent impacts that the burning of these types of fuels have on the environment, countries around the world are paying close attention to the development of renewable types of energy. Consequently, researchers have been trying to develop ways to take advantage of different types of clean and renewable energy sources. Wind energy production, in particular, has been growing at an increasingly rapid rate, and will continue to do so in the future. In fact, it has become an integral part in supplying future energy needs, making further advancements in the field exceedingly critical.

A 2 MW wind energy conversion system (WECS) is presented and has been simulated via the dynamic simulation software Simulink. This WECS consists of a 2 MW permanent magnet synchronous generator connected to the transmission grid through a power conversion scheme. The topology of this converter system consists of a passive AC/DC rectifier as well as a PWM DC/AC IGBT inverter, used to interface the DC link with the grid. The inverter has an integrated current control system for power factor correction to improve output power stability.

The described WECS enhances grid-side tolerance by buffering wind power disturbances demonstrated by its capability to isolate the grid from wind speed fluctuations. It also optimizes wind energy capture through harmonic filtering, enhancing output power quality. These findings have the potential to lead to further advancements including the capability for island operation and integration to a smart grid.

ACKNOWLEDGMENTS

I would like to show my gratitude to all those who supported me through this process, without whom, this would not have been possible. I would like to give special thanks to my advisor, Dr. Jiann Yuan, for his support and guidance throughout my project.

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CHAPTER ONE: INTRODUCTION

‘Alternative energy’, ‘sustainability’, and ‘green’ have become buzz words that are heard on an almost daily basis. This is mainly due to rising concerns about the impact humans have on the environment as well as the future state of the production and transmission of the power the world depends on. With the rising cost of oil and increasing demand for energy, countries around the world have taken the initiative to increase the production of ‘renewable’ types of energies. This has lead to an interest in the ability to capture energy from natural resources such as wind, water and sunlight.

Since there is insurmountable evidence of the many ways that the burning of fossil fuels pollute the planet, many are stepping up to the worldwide challenge of decreasing dependency upon them. According to the Global Status Report from the Renewable Energy Policy Network for the 21st Century (REN21), as of 2009, there were 85 countries with policy goals intended to increase the renewable energy usage and production [1]. The major types of ‘renewable energy’ described in these goals include wind, solar, hydroelectric, geothermal, and biomass.

To decide, then, which of these shows the most potential, researchers have analyzed several forms of sustainable energy, performing studies on the efficiency and productivity of each. Currently, solar and wind are a part of the most promising options for the near future and are therefore some of the most funded. The Electricity Industry Center at Carnegie Mellon (CEIC) boiled the question between the two down to ‘capacity factor’. Through the investigation of data collected over a two-year period, it was found that solar energy tends to have more short-term output power fluctuations and up to 20% less output capacity than wind

energy [2]. Findings such as this have led to substantial funding increases for the technological advancement of wind energy in particular.

Recent Growth of Wind Energy

In recent years, there has been quite a recognizable growth in the wind energy market. The World Wind Energy Association (WWEA) calculated in the 2009 World Wind Energy Report that, “The worldwide [wind] capacity reached 159,213 megawatts (MW), out of which 38,312 MW were added in 2009” [3]. Figure 1 below, shows the recent increase in wind energy production within the global market, including a prediction of expected growth for 2010 [3].



Figure 1 – Recent and predicted world growth of wind energy production

The United States, according to the WWEA, held the number one position for the total amount of installed wind energy in 2009 [4]. The American Wind Energy Association (AWEA)

also supports this in the 2009 Windpower Outlook, stating that in 2008, “42% of the new generating capacity added in the United States”, what equates to more than 8,500 MW, was from wind power, making it “one of the country’s largest sources of new power generation of any kind” [5].

Wind Energy Potential in the United States

In 2008, the United States Department of Energy (DOE) published a technical report about the feasibility of increasing the wind energy production in the United States to 20% by the year 2030. These findings were mainly dependent upon two things: that the investment required to integrate wind into the current transmission grid is modest, and that the wind resources across the nation be fairly accessible [6]. Table 1 describes wind classes according to the United States DOE’s National Renewable Energy Laboratory (NREL) and gives the corresponding wind speeds and power density capabilities [7]. Within the wind energy community, it has been accepted that a ‘good’ site for a wind farm is any area categorized as a Class 3 or above.

Table 1 – Classes of wind power density at 50 m

Wind Class	Power Density (W/m ²)	Speed m/s (mph)
1	0	0
	200	5.6 (12.5)
2	300	6.4 (14.3)
3	400	7.0 (15.7)
4	500	7.5 (16.8)
5	600	8.0 (17.9)
6	800	8.8 (19.7)
7	2000	11.9 (26.6)

Figure 2 is the latest wind resource map of the United States, developed by AWS Truepower, and it shows the potential for wind energy sites throughout the country [8]. This map unfortunately does not show the offshore siting capability the United States may possess. However, since offshore winds are historically more stable and blow at higher velocities, as the technology improves, the potential for offshore wind energy production is predicted to be possibly greater than on land.

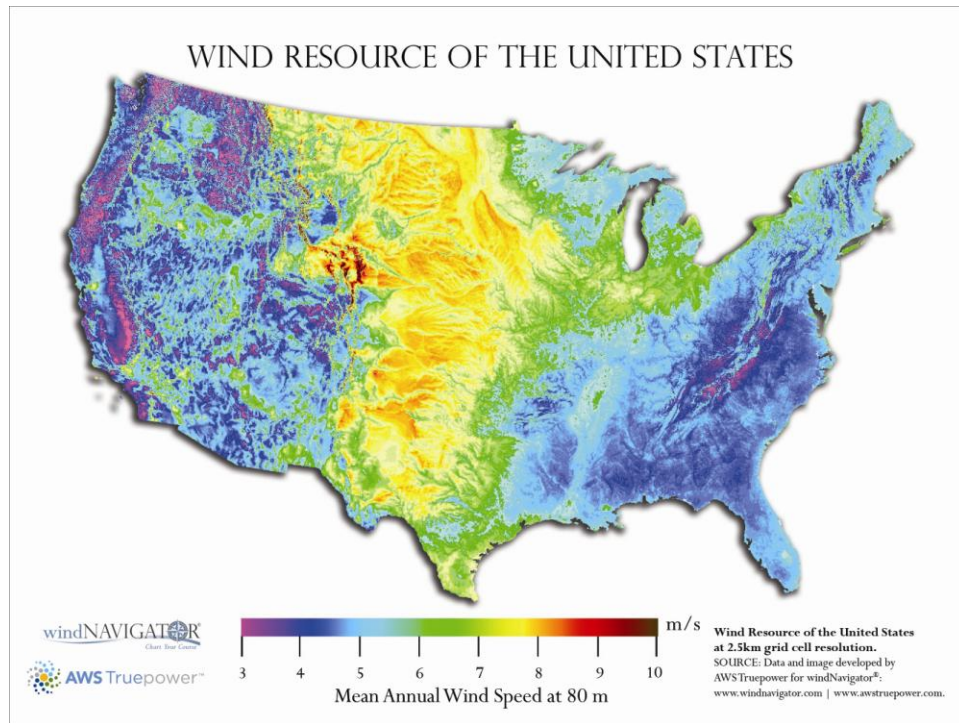


Figure 2 – Wind resource map of the U.S.

To continue, the United States government’s recent increase in support for renewable energy has become an integral part in the development of this industry. For example, to help meet new goals of increasing clean energy production, the United States federal government has extended the Renewable Energy Production Tax Credit of 2.1 cents per kilowatt-hour (kw-h) through 2012 [9]. This tax credit has been essential to the progression of wind energy in this country and will continue to be one of the primary driving forces behind its research and development. Furthermore, there is even a National Renewable Electricity Standard bill being considered in the U.S. House of Representatives, introduced earlier this year, which would “require utilities to generate or buy 25 percent clean, renewable energy by 2025” [10].

My Research

The research presented in this paper is the modeling and control of a wind energy conversion system connected to the AC supply grid. This has been accomplished through the dynamic simulation software MATLAB/Simulink created by MathWorks [41]. These simulations were created at a system level to gain a better understanding of how an entire wind energy conversion system works and what the challenges are for interconnection to the supply grid. Integration of multiple wind turbines, connected through the AC link, has also been presented as the foundation for a fundamental wind farm. The results presented here will be a basis for further research in this field.

CHAPTER TWO: LITERATURE RESEARCH

Wind has been used throughout history as a source of energy. Originally, windmills utilized this energy for chores like pumping water and grinding grain. In more recent years, however, this machinery developed into something known as a Wind Energy Converter (WEC). As the name may suggest, this device indirectly converts the energy extracted from wind into a usable form of electricity. The development of this type technology was relatively significant, later maturing into a multi-million dollar global industry.

A modern Wind Energy Conversion System (WECS) is shown below in Figure 3 and may consist of many different components [11]. In the following sections, each part of the system will be described in detail.

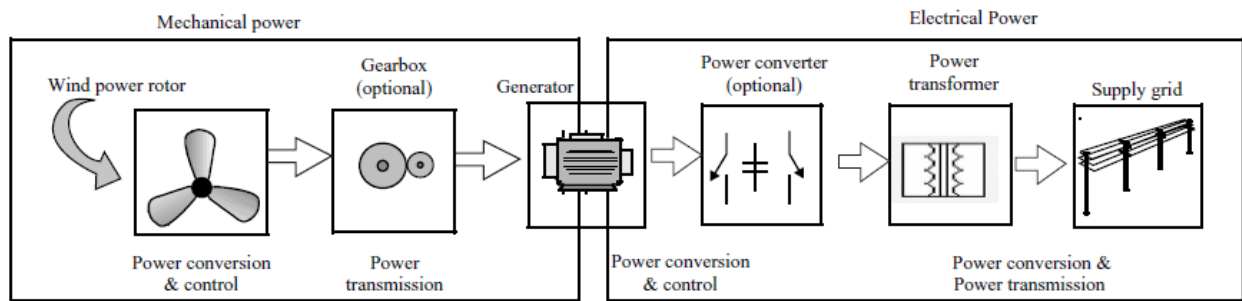


Figure 3 – Main components of a wind energy system

Wind Turbines

A wind turbine is the largest part of a WECS and is responsible for generating mechanical energy. The rotor is a subunit of the turbine and its function is the extraction of

energy from the wind and converting it into mechanical energy. The nacelle is located behind the rotor and houses the turbine's generating components, such as a gearbox. A gearbox can be used to step up the rotational speed of the slow moving rotor to values that are more acceptable to an electrical generator. However, gearless designs, which will be further discussed later in the chapter, are becoming very common, in which the gearbox is removed to increase reliability and reduce cost [12].

Wind turbines are designed to work at a certain range of wind velocities, this range varying slightly between designs and manufacturers. There is a particular speed which rotates the turbine enough to actually produce usable power, known as the cut-in speed, and is typically around 7 m/s. The rated speed of the turbine is usually around 12 m/s and is the speed at which the power conversion factor is greatest, lending itself to maximum power output. As can be seen in Figure 4, the rated speed is the point on the power curve where the output power begins to level out [13]. The cut-out speed is characterized as the point at which the turbine begins to shut down to prevent damage to the WECS, or roughly 25 m/s.

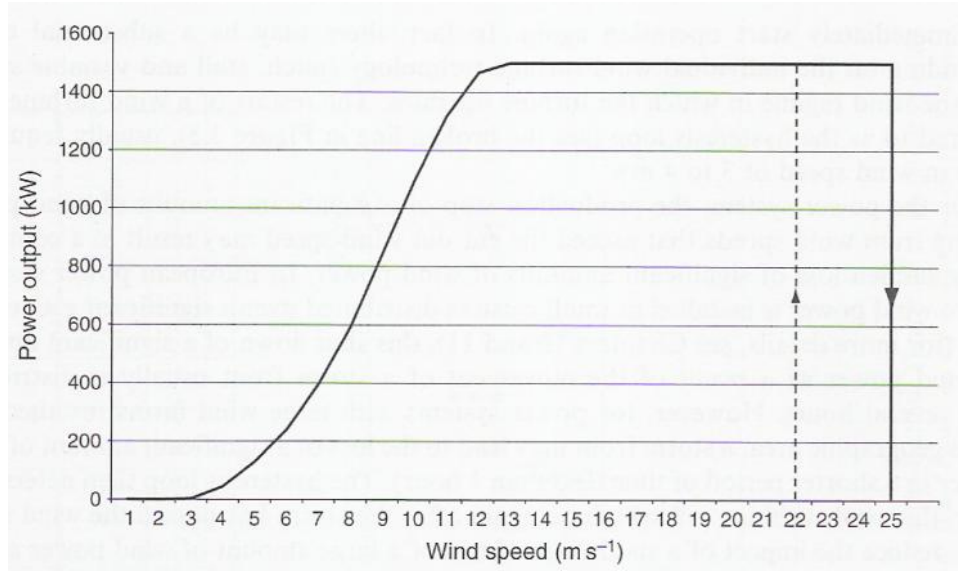


Figure 4 – Typical power curve of a 2 MW turbine

Power Extraction from the Wind

The magnitude of power that is contained within the wind at any time can be calculated by equation 2.1 below [13, 14]:

$$P_{\text{wind}} = \frac{1}{2} \rho_{\text{air}} \pi R^2 V_{\text{wind}}^3 \quad (2.1)$$

where $\rho_{\text{air}} = 1.225 \text{ kg/m}^3$ is the density of air, R is the radius of the turbine rotor and V_{wind} is the velocity of the wind [14, 16]. Figure 5 shows how an airstream typically flows around a downstream turbine [13].

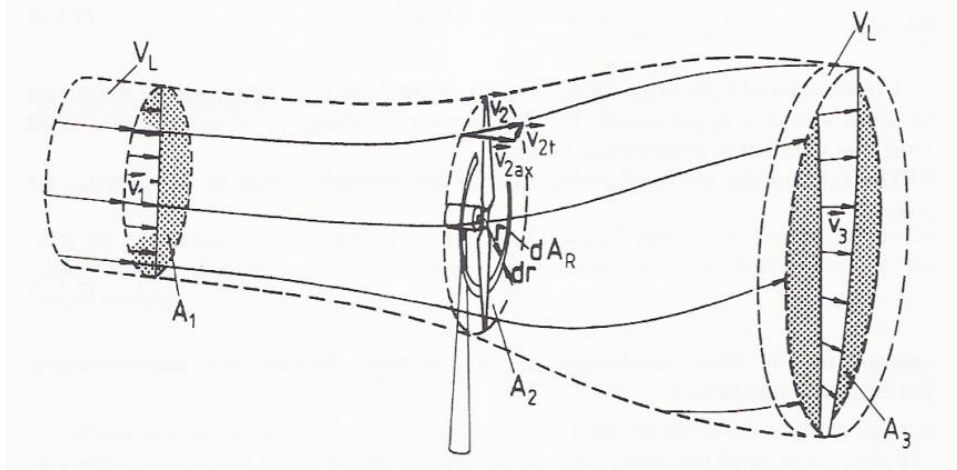


Figure 5 – Model of airstream around a downstream wind turbine

The turbine rotor then converts a fraction of this power, expressed as its efficiency or conversion factor $C_p = \frac{\text{power extracted}}{\text{power available}}$ into mechanical power as described in equation 2.2 [13,14]:

$$P_{\text{mech}} = C_p P_{\text{wind}} = C_p \frac{1}{2} \rho_{\text{air}} \pi R^2 V_{\text{wind}}^3 \quad (2.2)$$

A German physicist named Albert Betz calculated a theoretical maximum for mechanical power extraction from the wind by proving that maximum energy output is reached when $C_p = \frac{16}{27}$ or 59.3% [14]. Modern turbines have an electrical power efficiency coefficient of 46-48%, after gear and generator losses are accounted for [13, 12]. Figure 6 shows the power curve related to the efficiency factor [14].

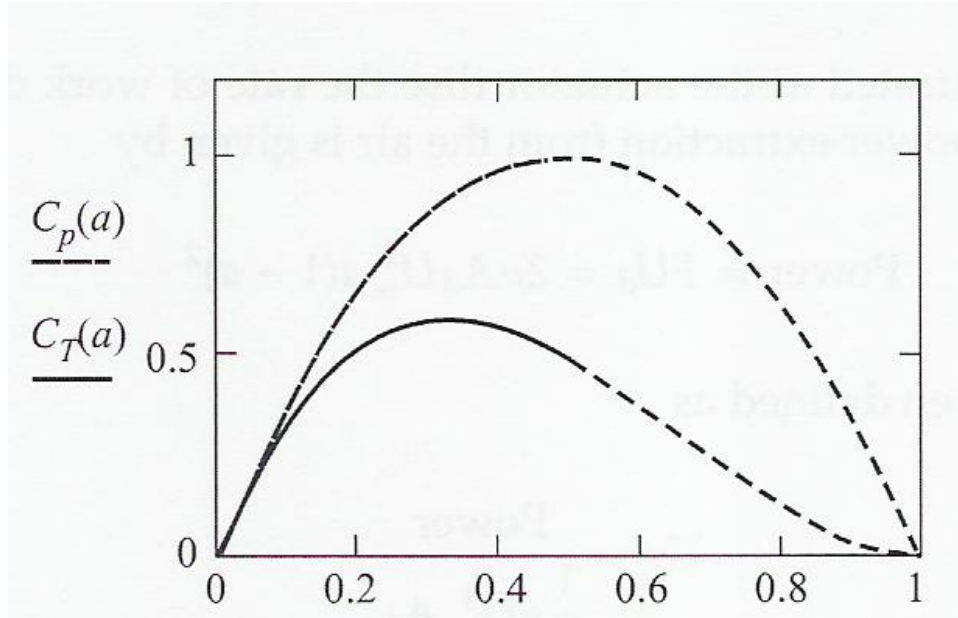


Figure 6 – Typical power curve related to C_p

Performance Control Through Turbine Manipulation

As engineers begin to fully understand wind energy conversion concepts, modifications are made to increase the amount of power generated per WECS. An example of this can be seen in equation 2.1, where the amount of power available from wind is shown to be a function of the velocity of the wind cubed. Therefore, even a small increase in wind velocity will lead to an exponential increase in available power. Wind velocity is typically greater at higher elevations because of “decreased effects from vertical wind shear (the rate at which wind velocity changes from one elevation to another) due to surface roughness (from trees, hills, buildings, etc.)” [15]. Therefore, to help drive down the costs associated with the production of wind energy, manufacturers have been increasing the height of rotors. Typical turbine height used to be around 50 m, now increased to 80-100 m [4, 15].

To continue, manufacturers are also trying to expand the length of rotor blades. The reason for this lies in the indirect relationship between the mechanical power output and something called the rotor tip-speed ratio (λ), as shown in equations 2.3 and 2.4:

$$\lambda = \omega_{\text{turb}} R / V_{\text{wind}} \quad (2.3)$$

$$P_{\text{mech}} = C_p \frac{1}{2} \rho_{\text{air}} \pi R^2 (\omega_{\text{turb}} R / \lambda)^3 \quad (2.4)$$

where ω_{turb} is the turbine rotational speed [16]. As can be seen, as the radius of the turbine rotor increases, the tip-speed ratio decreases, allowing for greater output power. For example Manitoba Hydro states, “to achieve the same power output as a turbine located in a class 6 wind resource, a turbine in a class 4 wind resource must increase the length by 40%” [15]. Typical turbine blade lengths have since increased from under 20 meters to over 200 meters [12, 15]. To mitigate the increased costs that would be associated with these increases, advancements in blade design have been essential to accomplish this goal, specifically the development of lighter and stronger rotor materials. Figure 7 below shows the increase in turbine height and rotor length (©Manitoba Hydro) [15].

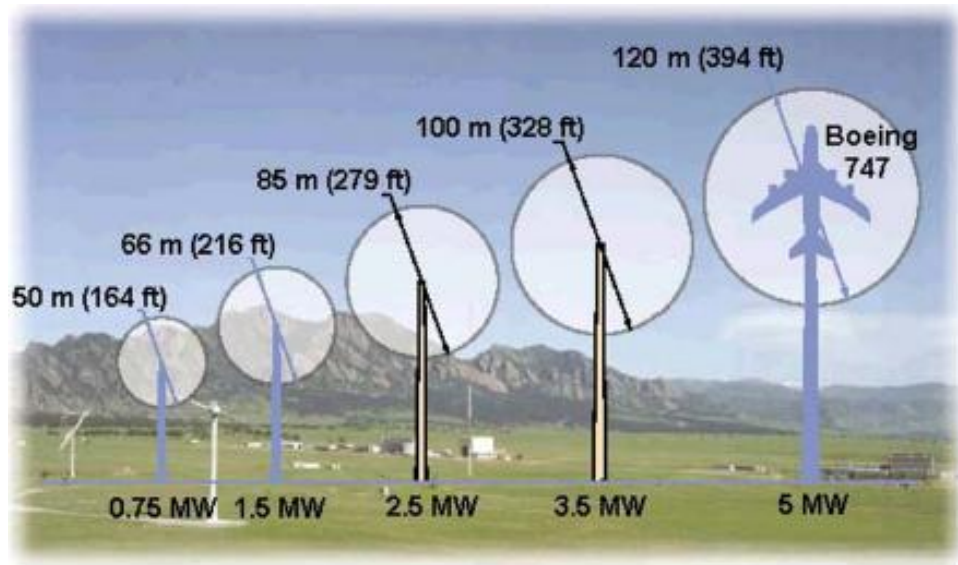


Figure 7 - Comparison of wind turbine sizes

Furthermore, WECS designers have begun manipulating another element for performance enhancement, the angle of incidence (ϕ). The angle of incidence is the angle between the plane of the rotor and the velocity of the wind relative to this plane. Shown in Figure 8 below is the relationship between the change in airflow pattern for a given angle of incidence and the blade radius [13]. Note that V_{tip} = rotor tip velocity, V_{rel} = relative wind velocity, α = angle of attachment, β = the blade angle.

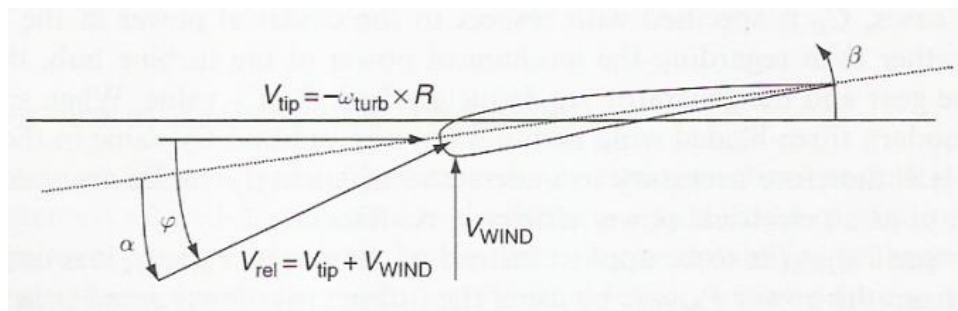


Figure 8 – Wind conditions around a moving rotor blade

The angle of incidence has a relationship to the tip-speed ratio, which then has a relationship to the mechanical power output, shown in equations 2.5 and 2.6 [16, 14].

$$\phi = \tan^{-1}(1/\lambda) = \tan^{-1}(\omega_{\text{turb}}R / \lambda) \quad (2.5)$$

$$P_{\text{mech}} = C_p \frac{1}{2} \rho_{\text{air}} \pi R^2 (\omega_{\text{turb}} R \tan \phi)^3 \quad (2.6)$$

The manipulation of this relationship started a new wave in wind turbine design. Since there is an ideal angle of incidence for every velocity of wind, designers have begun to implement the capability for dynamic adjustment of the rotor blade pitch angle (β), known as feathering [16, 14]. In essence, by changing this angle, the system is able to maintain a maximum conversion coefficient, therefore sustaining maximum power output. Figure 9 is an illustration of the relationship between the power conversion coefficient, the angle of incidence, and the velocity of the wind [16].

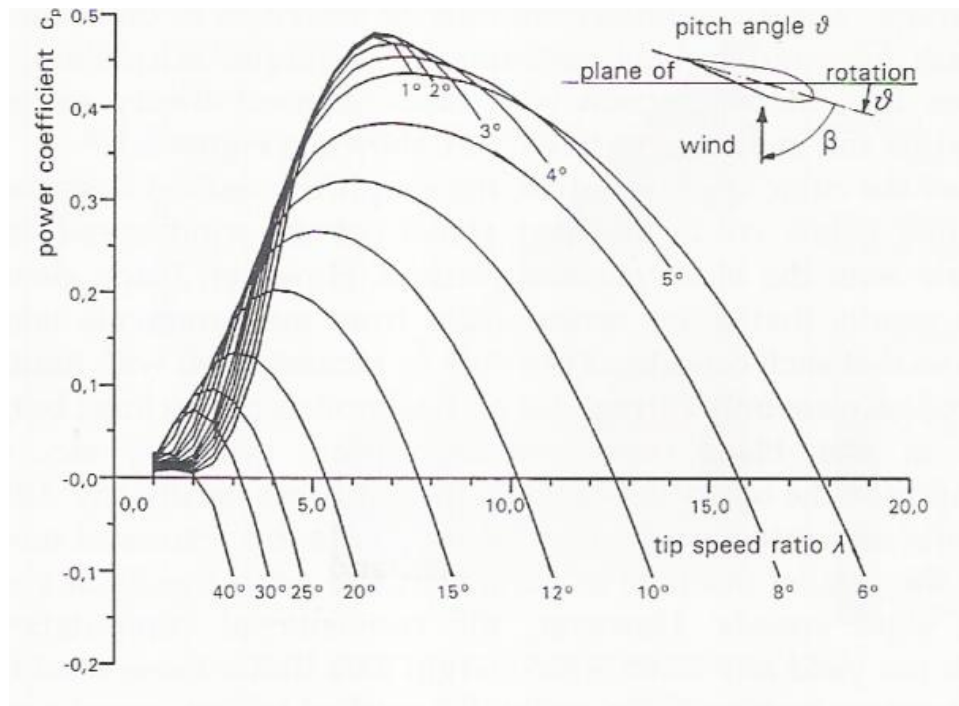


Figure 9 – Power coefficient of a typical turbine vs. tip speed ratio and blade pitch angle

Turbine Configurations

Wind turbine technology has undergone many changes throughout the years. To begin with, designers have tried varying the number of rotor blades; from single-bladed systems (better for high speed winds), to over 20 different blades per rotor (better for low speed winds) [16]. Designers have also tried modifying the rotational axis of the turbine. A vertical axis of rotation has been tried, but most commonly wind energy conversion systems use the more traditional horizontal axis of rotation [15, 17]. Illustrations of some of the different types of wind turbines can be found in Figure 10 below [16]. Correspondingly, each of these configurations had different performance output, and Figure 11 shows these different turbine types compared to the power efficiency coefficient [16].

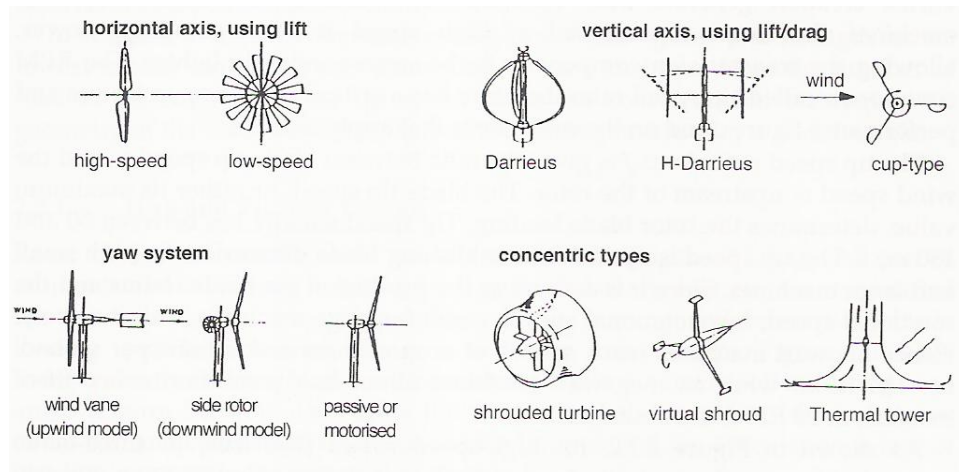


Figure 10 – Turbine configurations throughout the years

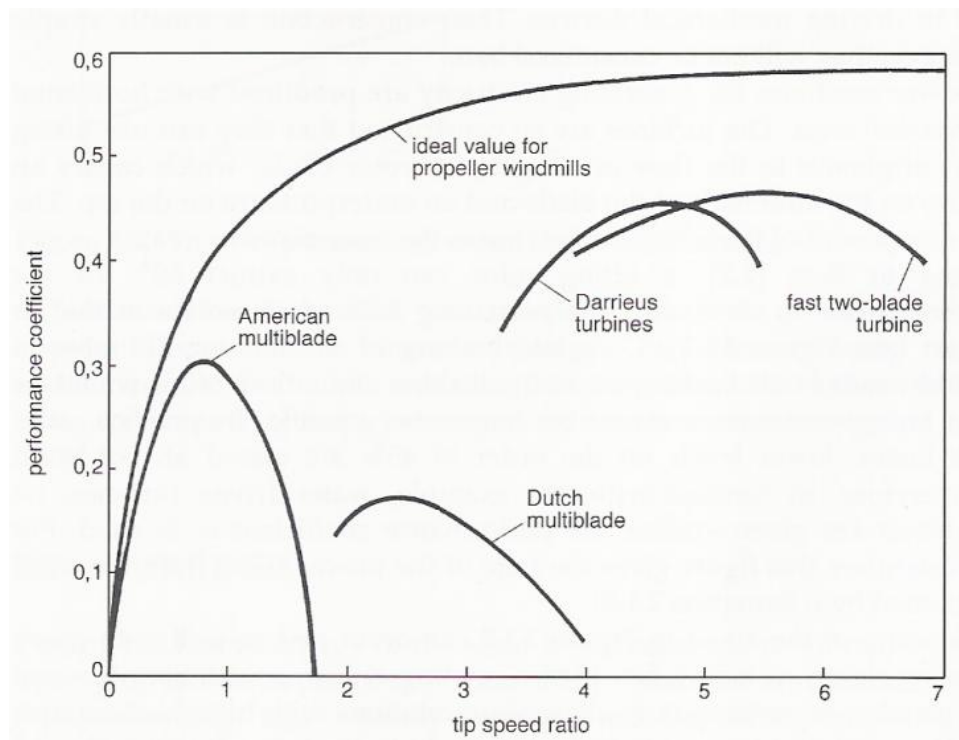


Figure 11 – Efficiency factor as a function of tip speed ratio compared to Betz limit

To continue, wind turbines have been modified to shut down at the designated cut-out speed. Some were designed with a yaw system, which incorporate a type of vane on the back of

the nacelle to physically turn the incident plane away from oncoming wind. Also, when manufacturers developed a dynamic system to manipulate blade pitch angel, they created a stall system, which will increase the blade pitch angle significantly, in order to bring the power back down to its rated value, shown in Figure 9 above. Examples of yaw systems are shown in Figure 10 above.

Electrical Generators

The electrical generator is the unit that converts the mechanical energy from the wind turbine into electrical energy. They are comprised of a stator, a static element, and a rotor, a rotating element.

Asynchronous

Asynchronous generators are also known as induction generators. The stator, in an induction generator, must have an external source of power to begin current circulation through its metal windings [16]. This external source is generally the supply grid itself. The circulating current, is sent to the rotor through a short circuit for initial excitation. The stator current will then produce a rotating magnetic flux, which will cause the rotor to spin in the same direction. However, the rotor will spin at a slightly slower speed than the magnetic field, and this is known as the slip of the generator [19].

Induction generators can only produce electricity when the rotor spins at a speed above the synchronous speed. The synchronous frequency is generally accepted as the frequency of the supply grid. For each generator, there is a speed which corresponds to this frequency, known as the synchronous speed [23]. With that said, however, induction generators have the ability to produce power at varying rotor speeds.

There are two types of commonly used rotors, the squirrel-cage rotor, and the wound rotor. The squirrel-cage rotor has current-carrying longitudinal bars around the shaft that are connected by rings, which look similar to a hamster wheel. These bars will spin in concurrence with the rotating magnetic field of the stator [16]. This type of rotor is more commonly used today due to the fact that they require less maintenance and are less expensive to manufacture.

The wound rotor induction generator is also known as a doubly-fed induction generator or a DFIG. This is because both the rotor and the stator have windings that participate in the electrical conversion process [19]. Slip rings and brushes electrically connect the two elements to transfer power between the shaft of the rotor and the electrical system [16]. These rings and brushes are the reason for the high maintenance required for these generators.

Synchronous

Synchronous generators are units that produce constant power at the synchronous speed. There is less maintenance required with these types of generators because they do not require slip rings or brushes to transfer electricity from the rotor to the electrical system [16]. They also do not require the supply grid to begin excitation in the rotor, so they can be run in ‘island

mode', or as the sole power generation facility. Synchronous generators can supply up to 100% of a facility's power requirements, whereas induction generators can only supply up to 1/3 because they depend on the reactive power from the supply grid [23]. Yet another benefit to the synchronous generator is that voltage regulation is possible, which is not the case with induction generators [16].

There are also different types of rotors for the synchronous generator family. The brushless wound rotor type is a modified version of the DFIG where the rotor still contains windings, but there is an internal DC source to begin excitation [19]. The internal exciter will begin the spinning of the rotor, which will then lock in to the stator's rotating magnetic flux and continue to rotate at the synchronous speed.

The permanent magnet synchronous generator uses a permanent magnet as its excitation field instead of an electromagnetic coil. These types of generators tend to be more expensive due to the material required to make them. However, the cost of the material continues to decline, and they are becoming more and more common in the energy industry due to their high reliability and low maintenance. Figure 12 demonstrates the difference between synchronous and asynchronous generators in torque and rotational speed [16].

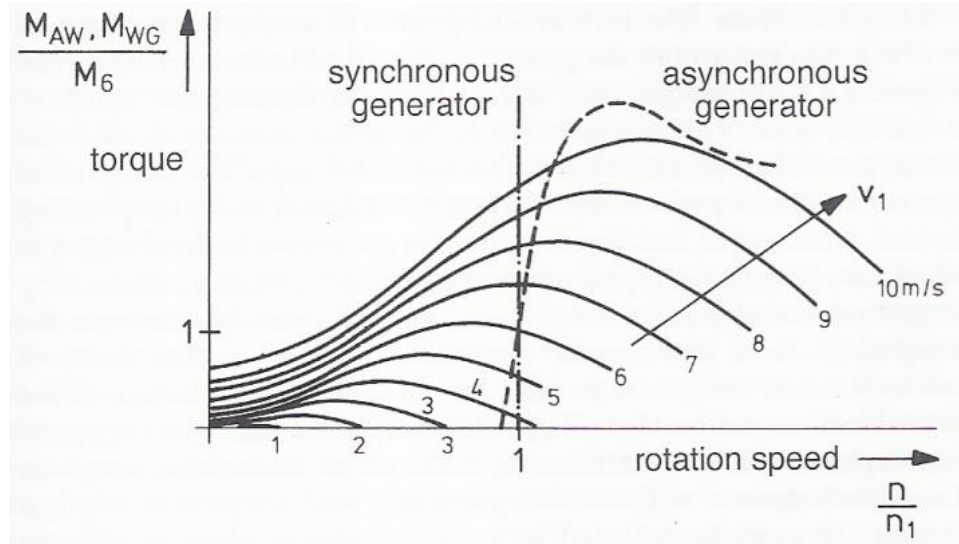


Figure 12 – Differences between synchronous and asynchronous generators

Power Conversion Schemes

Power conversion for wind energy systems generally occurs in two stages. The first stage is rectification, where the alternating current (AC) is transformed into direct current (DC). The second stage is where the direct current is transformed back into alternating current. Figure 13 is an example of a typical power conversion scheme for a permanent magnet synchronous converter (PMSG) (©2009 IEEE) [12].

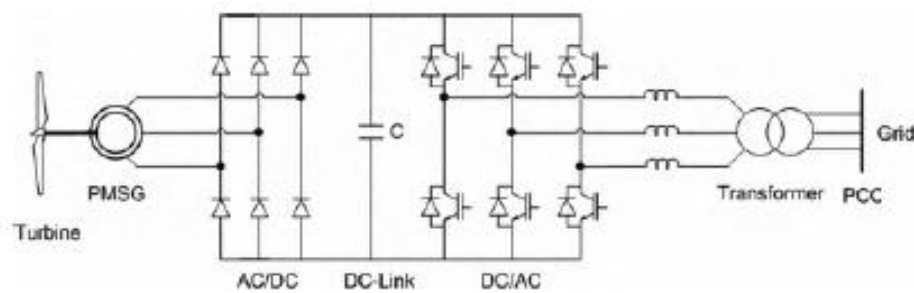


Figure 13 – Typical power conversion scheme for a PMSG

Rectification

Rectifiers are the first stage in power conversion, also called the AC/DC stage. The most basic form of a rectifier is a three-phase diode bridge, where the top diode will pass the positive cycle of a sine wave, and the bottom diode will pass the negative cycle of a sine wave, making both cycles positive. A single phase of the DC output can be calculated by the equation below [22]:

$$V_{DC} = 2V_{peak}/\pi \quad (2.7)$$

For a three-phase bridge, however, this will have to be multiplied by 3.

A rectification system can also be active, by using either MOSFETs or IGBTs as switching devices. These systems are more complex because they require switching signals, such as a pulse width modulated (PWM) signal. However, they tend to be slightly more efficient than the passive diode bridge, and a controls system can be incorporated through them, which will improve the power quality of the system [22]. A reservoir capacitor is typically used to smooth the output of the rectification stage, since the rectified waveform tends to still be somewhat sinusoidal. This is generally known as the DC link [22].

Inversion

The inversion stage is used to turn the output of the DC link back into AC. This is done through three phases of switching circuits, typically MOSFETs or IGBTs. This will produce

more of a square wave output due to the on and off nature of the switches [22]. Again control signals must be sent to the switches, typically done via PWM, and a control system can be implemented through them as well. The PWM scheme is most commonly used because of the possibility of voltage regulation, but it will also cancel out multiples of the third harmonic to help improve output power quality [13].

Direct AC/AC Conversion

There is a semi-unconventional method of power conversion that is available to designers known as direct AC/AC conversion. This does not require the intermediate DC link, which can both be bulky and possibly reduce the life of the system. On the other hand, it is less common due to the increased number of switches and the higher complexity in modulation and analysis [25]. The DC link in the typical power conversion scheme will decouple both stages providing easier control and creating a basically independent source for the inverter.

There are a couple different AC/AC converters available right now. The first is known as the direct matrix converter, which will perform voltage and current conversion in a single stage. This type of converter requires an especially complex modulation technique [25]. The second type is a modified version of the direct matrix converter and is known as the indirect matrix converter [26]. This style utilizes two stages for voltage and current conversion, but it still does not require an intermediate DC link. The separation of the stages allows for easier control, but it still involves more switching devices than the typical conversion scheme, making it more expensive [27].

Energy Storage

Since wind is a natural occurrence, caused by the warming of the earth, it can hardly be an ideal source of electrical power. For instance, wind behaves differently depending upon many elements such as location, climate, season, and even time of day [21]. To compensate for this and to help provide more constant power, storage systems have been implemented in wind energy conversion systems [20]. Since battery technology has been around and been improved for years, they are a less expensive choice, and therefore, more commonplace. Ultracapacitors, however, are an up and coming technology, and have also been tried. Ultracapacitors have a lower internal resistance, so they can provide a surge of power faster than a battery, however, batteries can provide power for a longer period of time [28].

Control Systems

Controls systems provide the ability to increase the efficiency of a wind energy conversion system and the quality of the output power. They are closed-loop feedback systems integrated into active power conversion stages to control the switching elements. DQ0 matrix transformations are sometime used to change the three-phase sinusoidal signals to DC signals for easier control [24].

Controls can be located at a number of places throughout the WECS. Initially, with an active rectifier, the rotational speed of the generator can be sensed and controlled through a proportional integration derivative (PID) controller. This will optimize the conversion

coefficient to maintain maximum power output [16]. Also, an early power factor correction circuit will help maintain power quality throughout the system.

Secondly, a controls system can be implemented through the grid-side inverter PWM signal. It can be used to maintain constant voltage on the DC link, which will decouple the grid from power fluctuations due to wind variations [20]. Control systems can also use output current feedback control to manage output active and reactive power for a full power factor correction approach [13].

A supplementary controls system can also be implemented for the addition of a storage system. The storage cells will connect through the capacitor bank, requiring a DC/DC conversion and controls system. This set of controls will maintain voltage regulation when the turbine is over producing power. It will also ensure proper power delivery during low or no wind situations [20].

Multiple Turbine Connections

The development of a wind farm occurs when multiple turbines are built in a common area and are connected together before sending the combined power to the transmission lines. Interconnection of wind turbines can be achieved in a couple of ways. First is through the DC link, which is typically used when also connecting in photovoltaic sources [39, 40]. The downside to connecting through the DC link is the increased size of the inverters required for power output to the supply grid. The second and more common connection method is through the AC link right after inversion [29-36].

Connecting to the Grid

It can be said, that in order to fully realize the potential that wind energy holds, it must be integrated into the transmission grid. This is especially difficult since the grid should be an extremely stable supply of power, and as discussed earlier, the wind is hardly an ideal supply source. As the wind speeds change, the turbine blades will spin respectively faster or slower, causing the output electrical voltage and frequency to also fluctuate. This can cause different types of power quality issues. Therefore, for wind to become widely used and accepted as a decent resource, these complications must be addressed.

To begin with, reactive power must be controlled, not only for input into the grid, but also for output from the grid. Since inductive generators require the supply grid to excite the rotor, it can draw a lot of reactive power from it, which can then make it become unstable [13]. Also, a low power factor will increase current in the line, the output of reactive power, and create losses within the system [16]. Power factor correction is one way of controlling the reactive power, which can be done through a control system on the grid-side converter.

To continue, harmonics are another problem for the transmission network, especially since harmonics are difficult for transmission companies to compensate for. Harmonics are responsible for increasing distortion in the network, which reduces the quality of power delivered to customers [13]. Filters are commonly used to remove most harmonic distortions for a clean connection to the grid.

Another issue with connecting wind turbines to the supply grid has to do with grid faults. When there is a fault in the electrical system, it is typical for wind energy conversion systems to disconnect from the grid, which is a non-ideal situation. As technology advances, it has become

possible to provide turbines with fault ride-through capability. This will disallow the WECS to disconnect from the grid, and instead provide reactive power to it until it can fully recover [32].

As the capacity for wind and the penetration into the electrical grid increases, these concerns become even more significant. Therefore, there have been new changes to the transmission system standards to help maintain the quality and integrity of the energy being distributed across the country. Institute of Electrical and Electronics Engineers (IEEE) 1547 series of standards have been updated to include renewable energies [37]. This series is particularly related to performance, operation, testing, safety considerations, and maintenance of the interconnection. An international committee, the International Electrotechnical Commission (IEC) has also updated a series of standards, known as the 61400 series, regarding wind energy in specific [38]. These standards are involved with preserving the quality of safety, performance, noise, structural testing, and power quality.

CHAPTER THREE: METHODOLOGY

The wind energy conversion system presented in this paper begins with a 2MW permanent magnet synchronous generator. It is followed by a passive rectification system as well as a 5 Farad capacitor bank. The inverter chosen for this project is a PWM controlled set of IGBTs with incorporated controls system. Following that is a harmonic filter and a step up transformer connected to the AC supply grid. Figure 14 shows the block diagram of the entire wind energy conversion system.

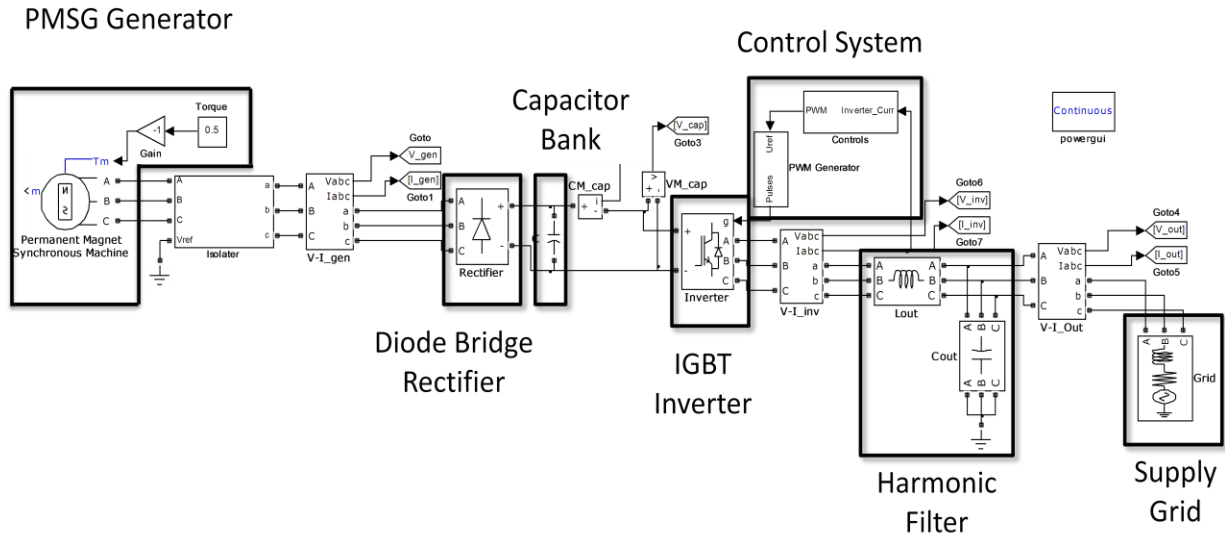


Figure 14 – Schematic of full wind energy conversion system

The input to the permanent magnet synchronous generator (PMSG) was chosen to be a constant torque, which is a simulated output of a wind turbine. From there the electrical current runs through a diode bridge for full rectification. A 5 Farad capacitor bank was chosen to smooth the waveforms from the rectifier to charge to a constant voltage. Afterwards, this

electrical energy is transformed back into AC through a full bridge IGBT inverter. This inverter is fed by a PWM signal to control the switches. The PWM signal is a series of six signals (two for each set of IGBTs), which change widths depending upon the modulation waveform. When the value of the reference signal, or the sine wave, is greater than the modulation signal, the PWM signal is in a high state (or a logical 1). Otherwise, it is in a low state. An example of this is shown in Figure 15 below.

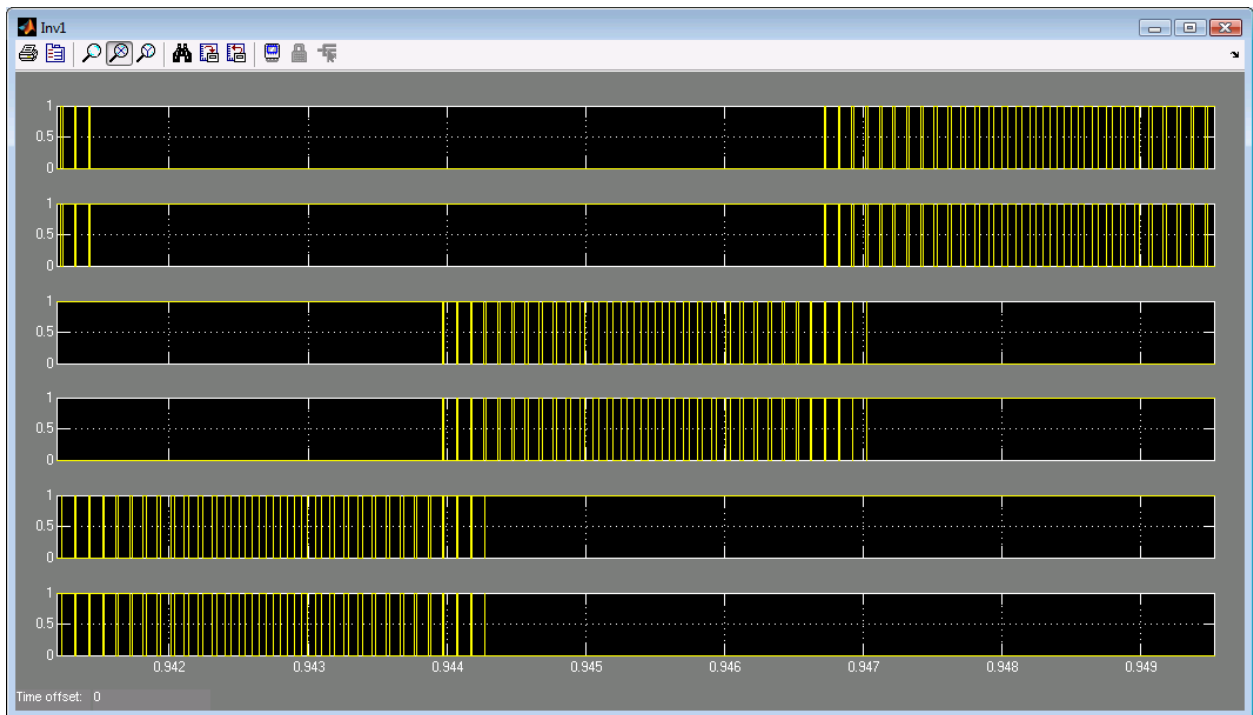


Figure 15 – PWM signals controlling the inverter bridge

The control system in place will then detect the output current of this inverter and convert it into a per unit denotation. This three-phase sinusoidal signal will be transformed into the rotating reference frame of DQ0. Here the direct current is related to the active power output and controlled to 1 via a PID controller. The quadrature current, on the other hand, uses a similar

PID controller, and is brought to 0. This will help maintain a high power factor for a better quality output power. An example of the control system in place is shown in Figure 16 below.

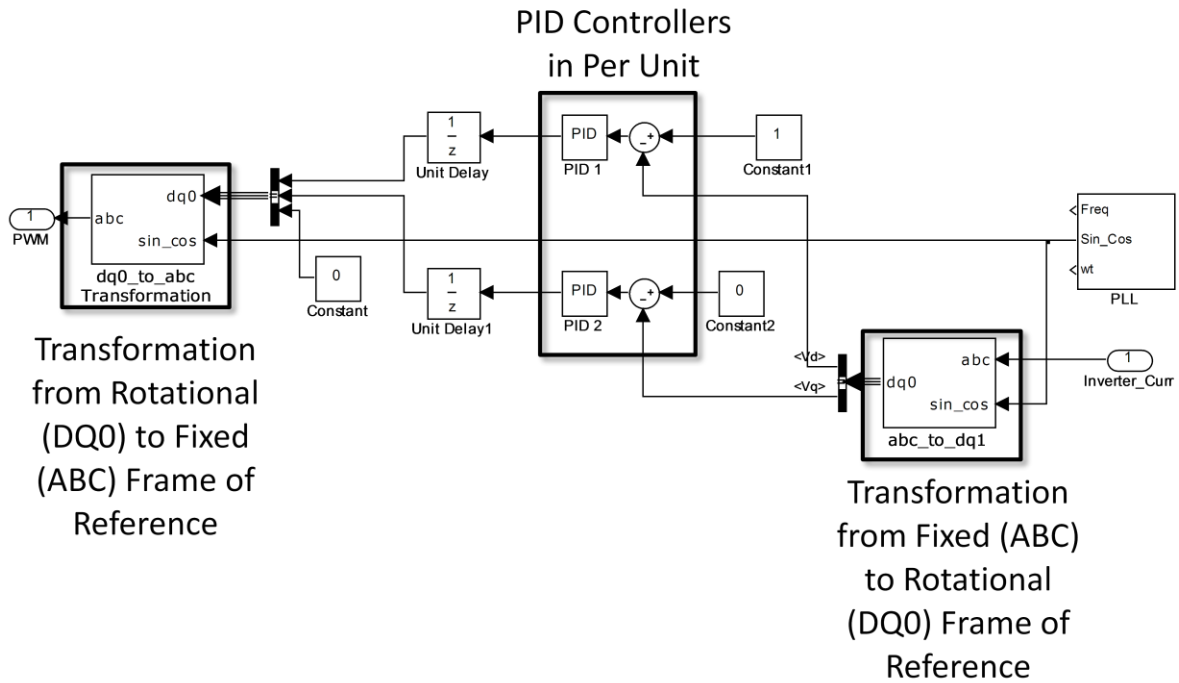


Figure 16 – Control system used for PWM inverter

The controlled output of the inverter will then feed into a harmonic filtering system. This filter has been tuned to the grid frequency, or 60 Hz. A multiple of this frequency, namely 20 times this frequency, was used to help better filter the harmonics created by the on/off output of the switches. This is then fed into the AC supply grid, chosen as 4 kV, which is commonly used for low voltage transmission.

A fundamental wind farm was also simulated, by connecting three generators together. However, since the connection was made at the AC point, only the second half of the systems is shown. An example of this can be seen in Figure 17 below.

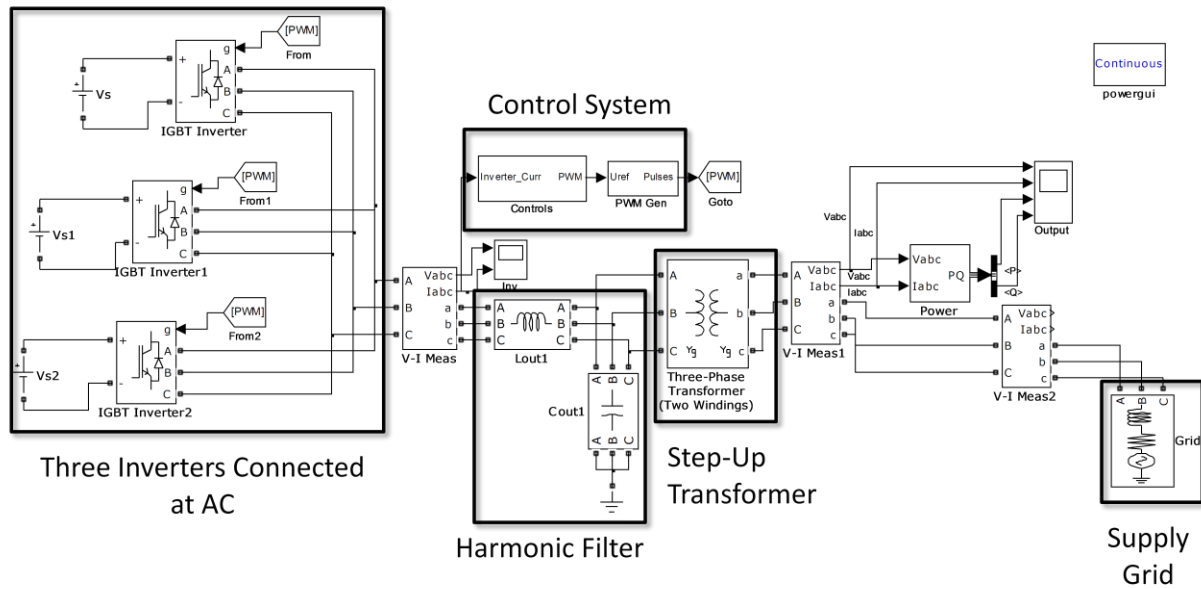


Figure 17 – Multiple WECS connected at the AC link

Unfortunately, as the inverters switch, it is not certain that all combined signals will be in phase with each other. Therefore, as can be seen, only one control system and one set of filters are used to maintain power quality for the output. In this simulation, a step up transformer is used to convert the 4 kV to 33 kV, which is for medium to high voltage transmission. Afterwards, this electrical power is connected to the AC supply grid, as shown on the right of the figure.

CHAPTER FOUR: RESULTS

As stated previously, the initial WECS demonstrated in this work was the system-level simulation of a single 2 MW permanent magnet synchronous generator. It contains all the stages necessary for power conversion to connect to the AC supply grid: rectifier, DC link, inverter, control system, and harmonic filter.

Single Generator

The input for this single PMSG is a constant mechanical torque. Figure 18 and Figure 19 below show the output of the generator and capacitor bank, respectively. As can be seen, the output of the generator is a three-phase sinusoidal signal which holds a voltage of approximately 4 kV. The DC link voltage is a smooth 7.3 kV.

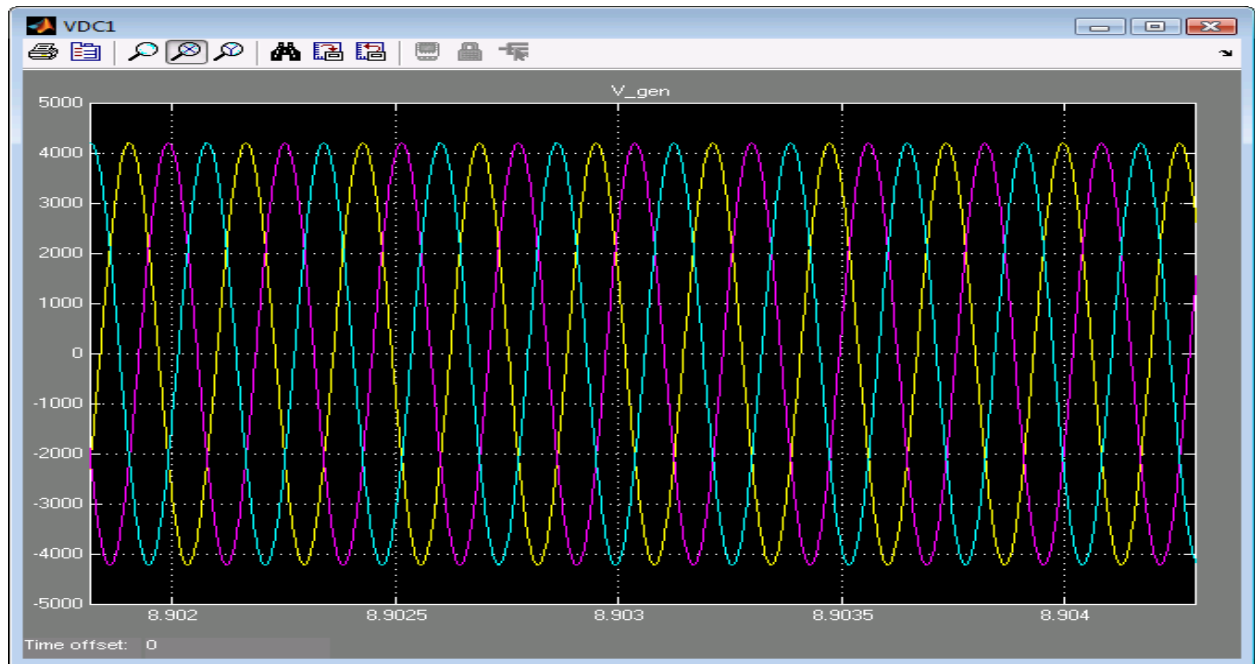


Figure 18 – Output waveform of the PMSG with a constant torque input

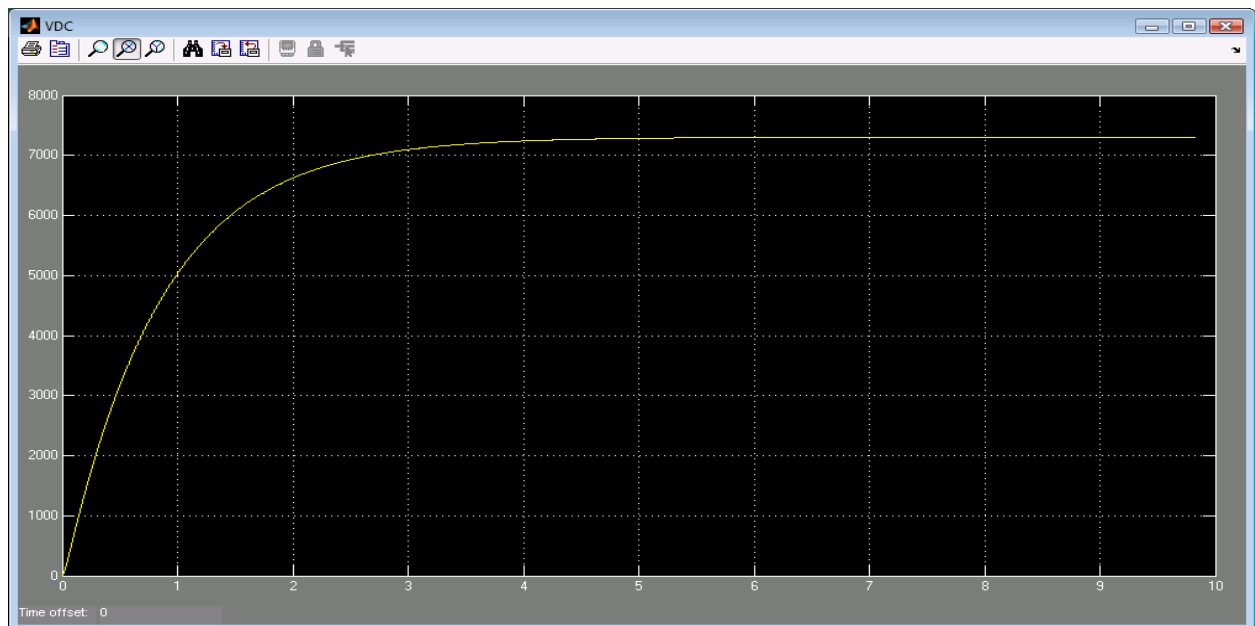


Figure 19 – Output waveform of the capacitor bank with a constant torque generator input

A non-constant torque was also used to simulate how the system would react to fluctuations in wind. A step up mechanical torque was applied to the PMSG at 7.5 seconds, and Figure 20 and Figure 21 below demonstrate how the outputs begin to increase at 7.5 seconds.

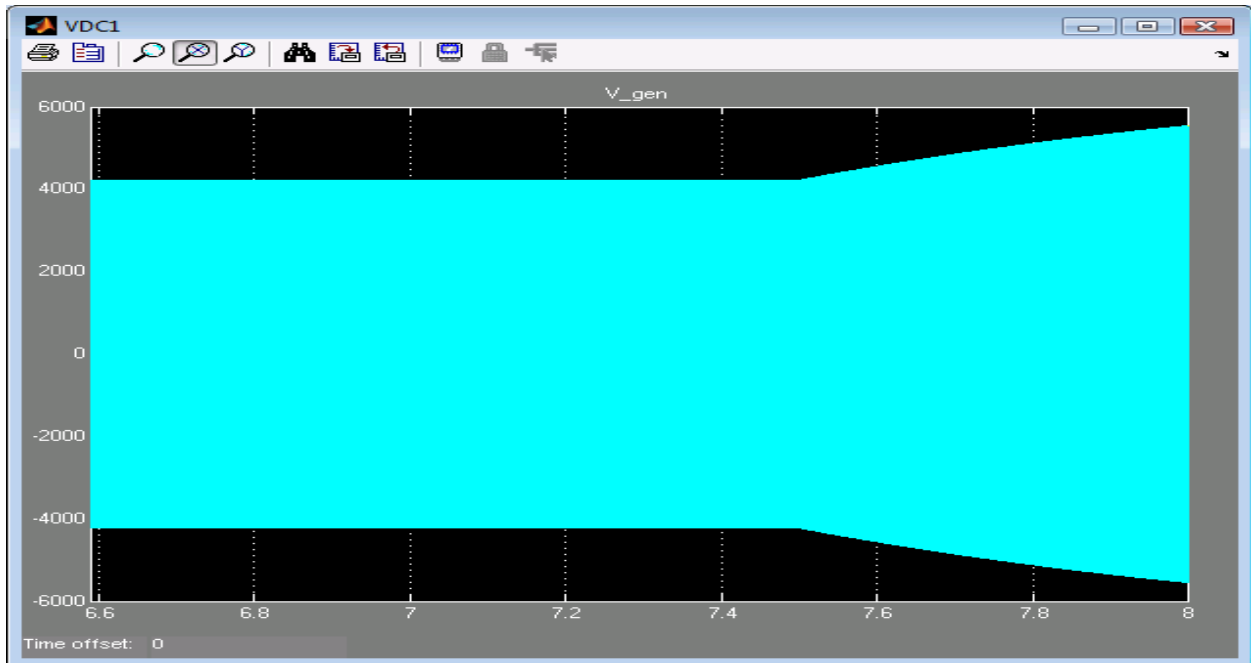


Figure 20 – Output waveform from the PMSG with a step up torque input

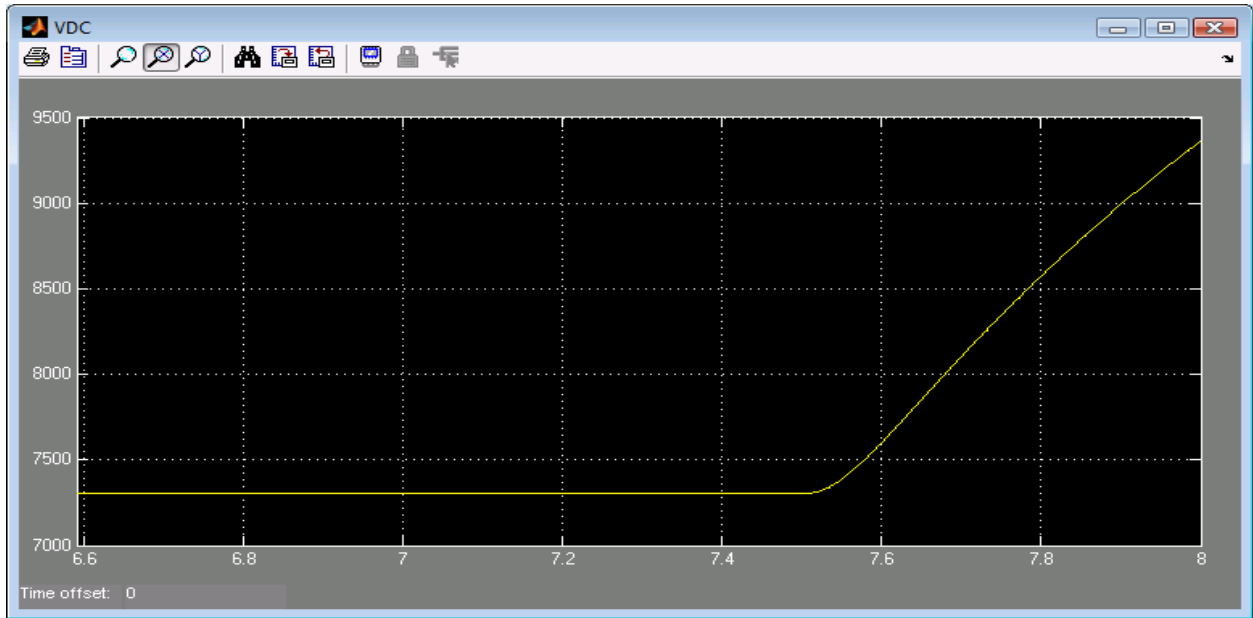


Figure 21 – Output waveform of the capacitor bank with a step up torque generator input

Figure 22 below is a multi-plot of the output signals of the system, with the variable torque replaced with a constant torque once again, and without any filters or controls. The first plot is the output voltage, which is an unclean 33 kV. As can be seen, without the harmonic filters, the output is essentially a square wave due to the switching nature of the inverter. The second plot is of the output current, and while this is a clean 2 kA, it is not in phase with the output voltage. Both the unclean output voltage and the low power factor lead to an unstable output active power (P), plot 3, and a large, also unstable, reactive power (Q) output, shown in plot 4.

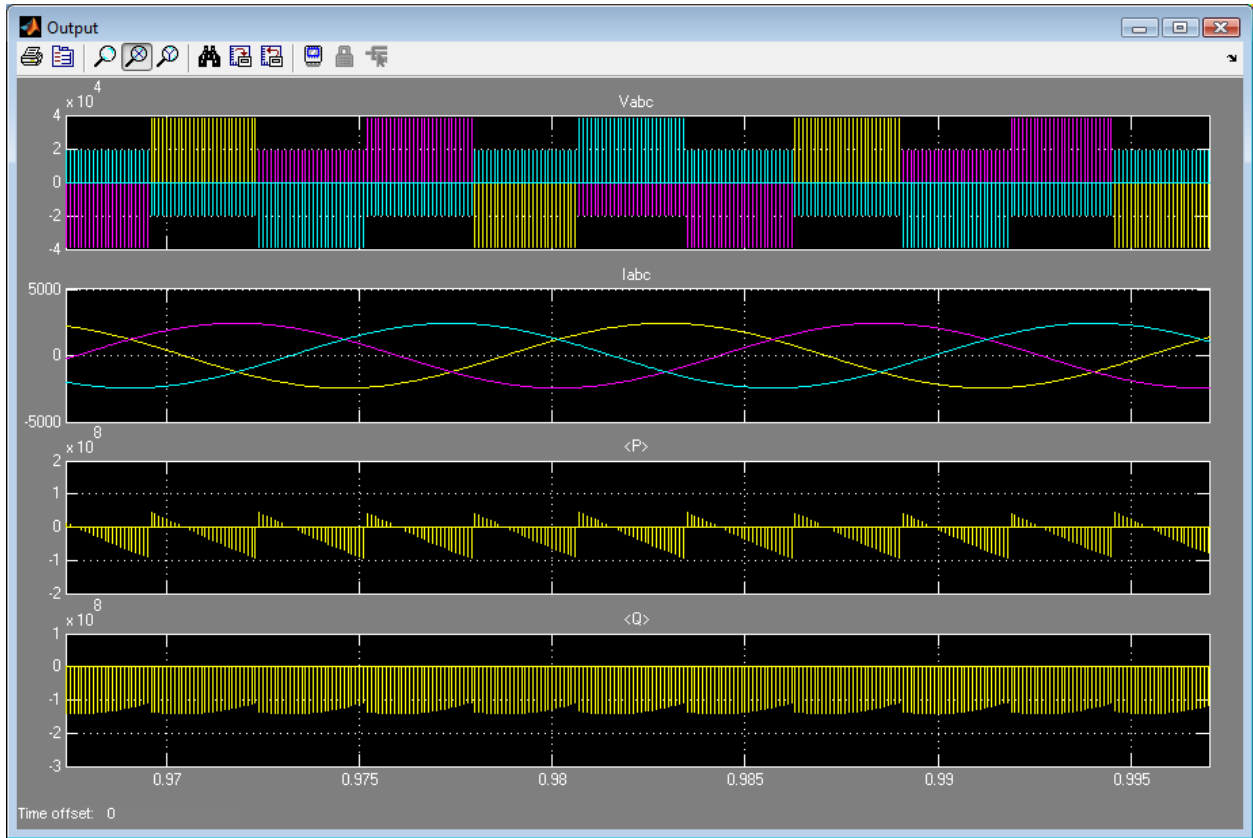


Figure 22 – Output waveforms of the system, shown without filters or controls

Figure 23 below is a demonstration of how harmonic filters added to the output of the inverter will clean up the output voltage, which is shown at 25 kV in plot 1. Plot 2 demonstrates a clean output current of 200 A. Both the voltage and current magnitudes are a bit smaller than the previous figure due to the inductive and capacitive elements of the filter. Plots 3 and 4 show a cleaner output active and reactive power, but they are still quite noticeably unstable as they are highly sinusoidal. This is a non-ideal situation for connecting to the supply grid.

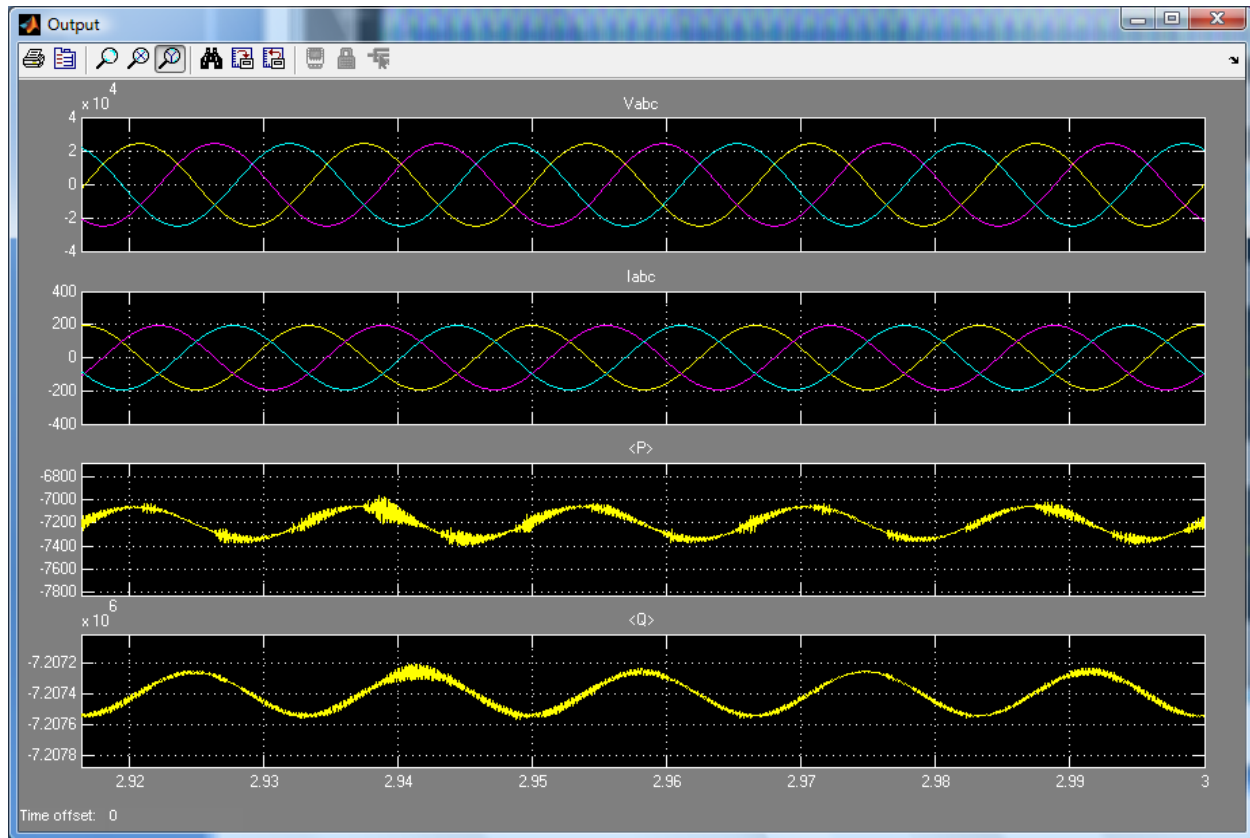


Figure 23 – System output waveforms with harmonic filter, but without a control system

Figure 24 below shows the output of the systems when both a harmonic filter and a control system are implemented at the output of the inverter. As stated before, the controls system senses the output current and feeds the controlled version back to the PWM generator for the inverter switches. Plot 1 demonstrates a clean output voltage, controlled to 33 kV, which is acceptable for a medium to high transmission system. The output current, shown in plot 2, is a clean 50 A sinusoid, which is in phase with the output voltage. Plot 3 is a stable active power output with a magnitude of 2 MW, which demonstrates the optimization of the generator output, rated at 2 MW. The reactive power output is shown in plot 4, and although it is not exactly 0, it has been controlled down to 100 kW, which allows for a much better connection to the supply

grid. The sinusoidal element shown in this plot is due to the small amount of ringing still present in the voltage and current. This can be taken care of with a more sophisticated set of filters and controls.

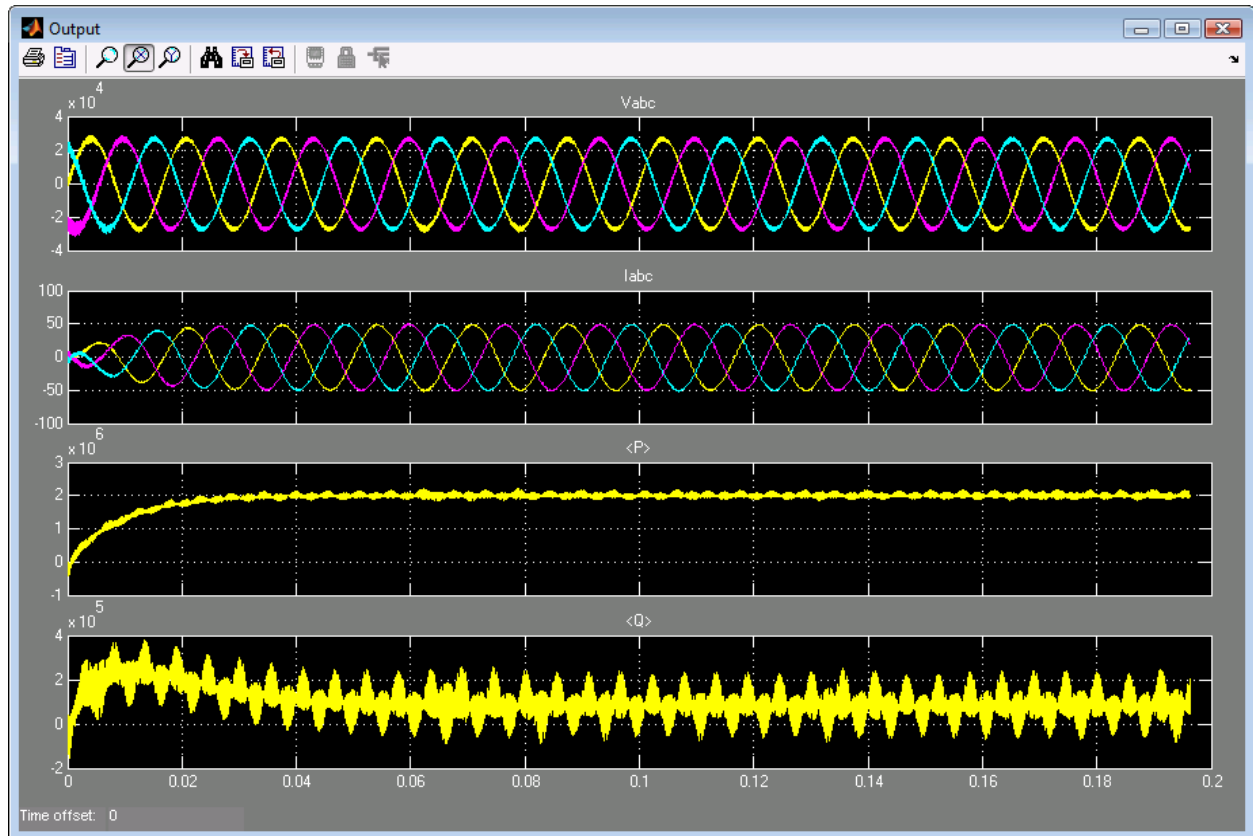


Figure 24 – Output waveforms of the system with added output filters and controls

Multiple Generators

A small wind farm was simulated in this work, connecting three generators at the AC link following the inverter. As the generator output and the DC link voltage will not change for each of the systems, these plots are not shown. However, the connected output waveforms are shown

in the multi-plot Figure 25 below. A single harmonic filter and a single set of controls were used to ensure the power quality before entering the supply grid. As there is no way to verify each inverter output phase will line up with the next, the single set of controls is extremely important. Shown in the methodology section of this paper, the output current of the combined signals is sensed and simultaneously fed back to each of the inverters for full control.

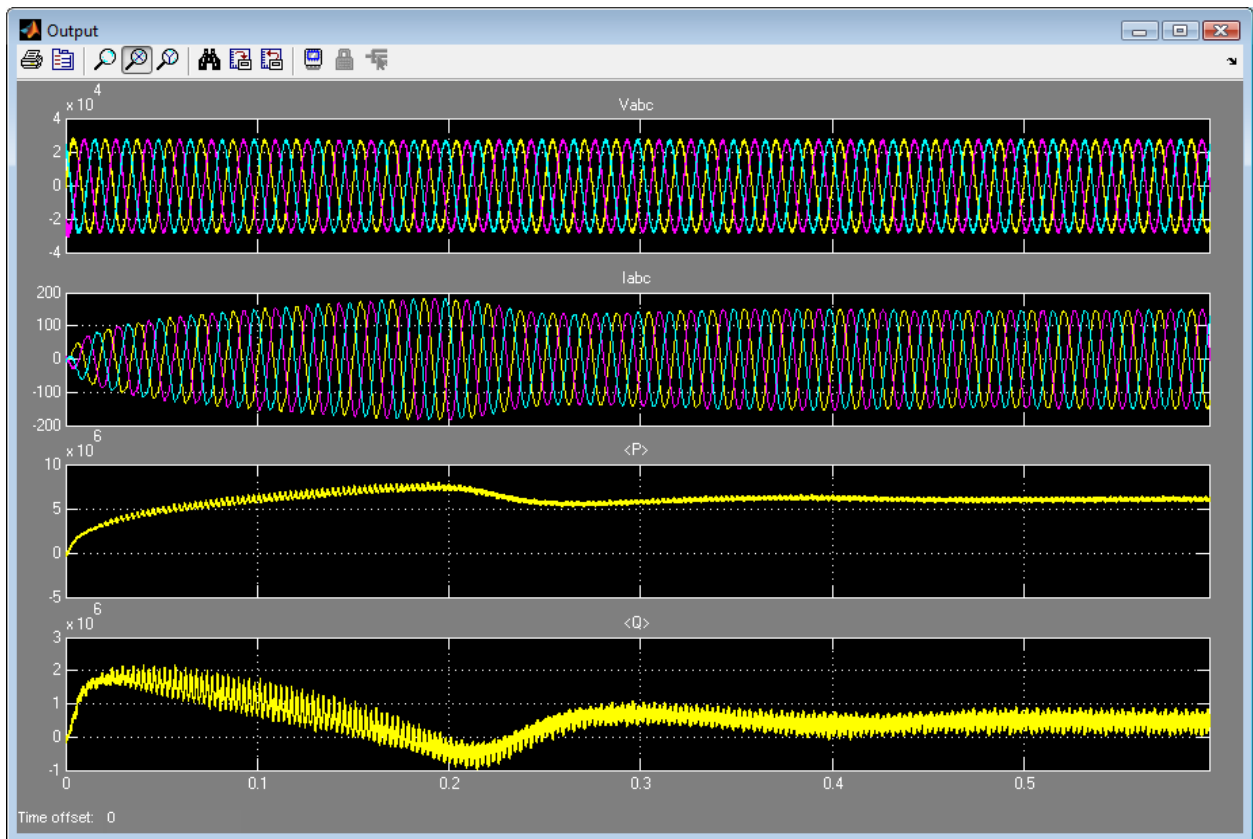


Figure 25 – Output waveforms of 3 PMSGs connected through the AC link

Plot 1, of Figure 25 above, shows the same clean 33 kV output voltage, while plot 2 demonstrates the multiplication factor of 3 with the clean 150 A output. Plot 3 also shows this same multiplication factor with a stable 6 MW active power output. Plot 4 shows the reactive

output power being controlled down to 500 kW, which, as stated before, can be improved with a more sophisticated set of filters and controls.

CHAPTER FIVE: SIMULATION DIFFICULTIES

Modeling and simulation of a system has its share of difficulties. To begin with, the simulation software Simulink has limitations. The built-in blocks are just estimations of how parts of the system should work, and are not fully capable of real world modeling. Therefore, to insert full losses of these pieces, self modeling will be necessary. For example, interconnecting multiple turbines/generators to the DC link will not completely work as the capacitors do not necessarily emulate energy stored within the element. Instead, a voltage difference is apparent, but when controlling the voltage through the rectifier, an effective increased power will not be present.

Secondly, Simulink has some limitations as to which blocks can be connected together. For example, simply adding a rectifier to the output of the PMSG will not work. Instead, the work presented in this paper included an isolation block, where the voltage and currents ran through controlled voltage and current sources to decouple the output of the generator from the input of the rectifier. This had the unfortunate consequence of substantially increasing the simulation time.

To continue, as was stated before, the rectifier and inverter blocks were limited as to how they were originally modeled. Specific switching devices could not be chosen, therefore the rated power of both were simply estimations. For that reason, to include proper losses and limitations of a real system, these stages would have to be modeled independently.

Additionally, blocks such as the transformer and the AC grid were created in a way that disallowed them to act as one would think. The step up transformer, for instance, required a lot of internal tweaking to perform as expected. Also, the three-phase supply grid used in this work

did not perform the same as three single AC supplies. It was found that the three-phase supply block worked much smoother than separate supplies, though the reason for this is still unknown.

Furthermore, the controls system also proved to be a bit tricky. First, the phase-locked loop (PLL) required for creating the sine/cosine vector needed for the ABC-DQ0 transformation would not work when supplied from the grid. The PLL should be sourced from a robust signal, but the AC grid did not prove to be strong enough, so an ideal PLL was used for this work. Second, the feedback controls rely on past input, so the beginning of the simulation would veer off into singularities. Therefore, a unit delay was implemented to overcome these issues.

Finally, simulation times proved to be problematic for this work. The generator-side of the system would take hours to run. Presumably the isolator block was cause for a great deal of this, but even simple error analyses were challenging due to the long wait time for each simulation run. Even tricks such as setting an initial value for the capacitor bank, to reduce the simulation time required to charge the capacitor, would not succeed. Simulink could not handle an already charged element at the start of the system, and would produce erroneous waveforms for the output. Therefore, concentration on this aspect would be required for further work on this WECS.

CHAPTER SIX: FURTHER RESEARCH

As the WECS presented in this paper is a somewhat unsophisticated approach, with more time and resources, further work could definitely be accomplished. To begin with, a storage system should be implemented to ensure constant power output during low or no wind situations. This will require not only another DC/DC conversion stage at the DC link, but also another control system for proper performance. Secondly, some form of fault ride-through capability should be employed to guarantee conformity to new grid standards. The WECS should provide reactive power to the grid until it can recover from the fault.

To continue, a more sophisticated harmonic filter and control system should be realized to help control reactive power down even more. The harmonic filter will help with ringing in the voltage and current output, and the control system should bring the power factor up to nearly ideal. An IEEE white paper was consulted for this type of further work and an example of a more complex control system is shown in Figure 26 below (©2008 IEEE) [20].

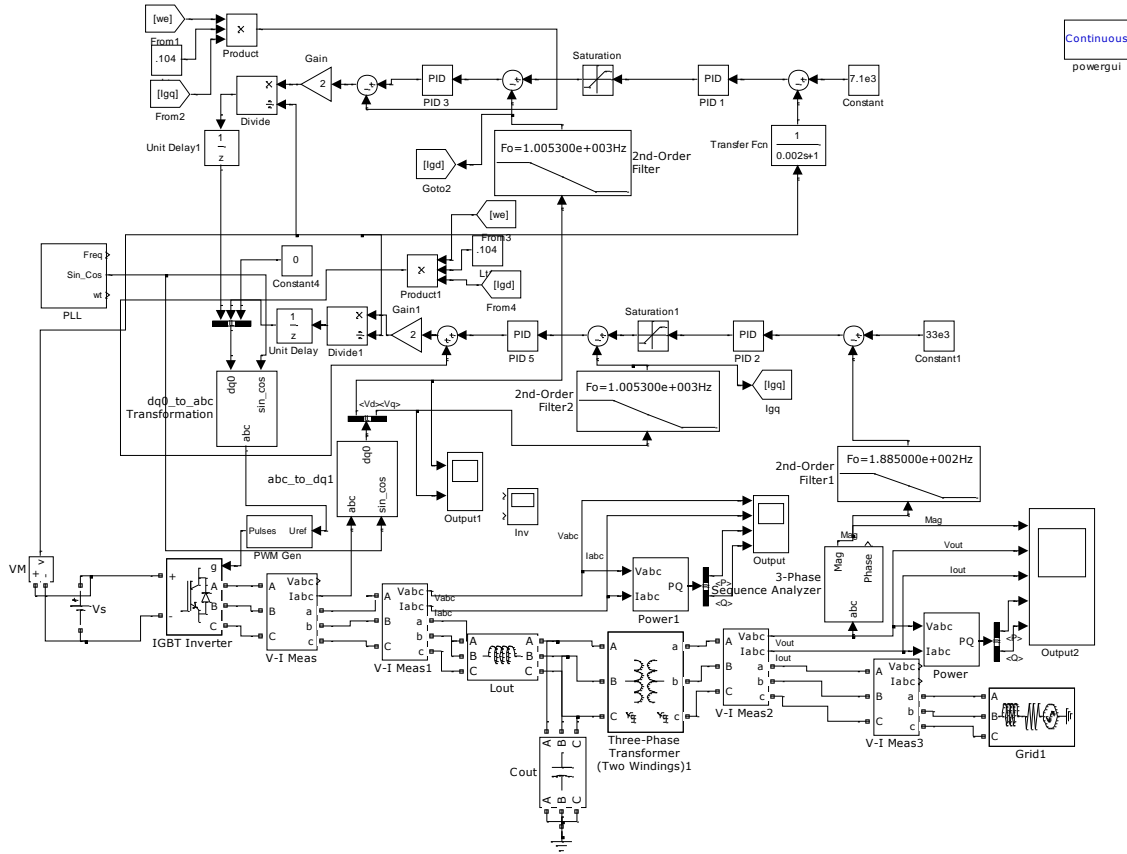


Figure 26 – Complex control system implemented through the grid-side inverter

Controls such as the set shown in Figure 26 above, will provide for DC link voltage preservation, so when the wind source fluctuates, the DC link will remain fairly constant, effectively decoupling the supply grid from the non-ideal source. It should also provide for frequency compensation during droops in the grid. An added active rectifier with PWM controls would help maintain maximum power coefficient to increase efficiency of the WECS as well.

Finally, by using a different dynamic simulation software or by individually modeling the blocks seen in this paper, losses and limitations can be included in the model. This will help gain a better understanding of how a WECS will act in real world conditions. Even adding an actual

wind turbine model in front of the generator will help gain knowledge of how tolerant the conversion system will be to simulated wind fluctuations.

CHAPTER SEVEN: CONCLUSION

It is clear that wind is becoming a staple within world energy production, requiring a continual need for research and development. These next few years will prove to be some of the most important in development of renewable energy, especially wind. In order to fulfill these strong predictions, attention must be paid to increasing the efficiency of wind energy capture, which is what has been researched and presented in this paper.

Besides the fact that these types of goals will help reduce the amount of pollutants released into the environment, they also promote energy stability and economic security through the global reduction of reliance on fossil fuels, the creation of an export commodity, and the expansion of the job market. The work presented in this paper is a great beginning to understanding this type of energy conversion. Further work will lead to a more thorough model for a real world wind farm connected to a supply grid. This can even develop into the modeling and control of wind energy penetration into a smart grid.

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Wind Power in Power Systems

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Grid Integration of Wind Energy Conversion Systems

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A02_Last_Name: McCartney
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A07_Zip: 32816
A08_Country: USA
A09_Contact_Phone_Number: [REDACTED]
A10_Fax:
A11_Emails: [REDACTED]
A12_Reference:
A27_Book_or_Journal: Book
A13_Book_Title: Wind Energy Handbook
A14_Book_Author: Tony Burton
A15_Book_ISBN: 0471489972
A15_Book_InStockDate:
A16_Journal_Month:
A17_Journal_Year:
A18_Journal_Volume:
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A20_Copy_Pages:
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How New Technology Developments Will Lower Wind Energy Costs

Knights Email Print Message

Page 1 of 2

RE: CIGRE Canada - Request from a student

From: **Hoffman, Dana** (danahoffman@hydro.mb.ca)
Sent: Wed 10/20/10 8:44 PM
To: [REDACTED]
Cc: Lafreniere.Suzanne@hydro.qc.ca; Molinski, Tom (tsmolinski@hydro.mb.ca)

Dear Shauna,

We don't have a problem with you using a graphic from our presentation named "How New Technology Developments Will Lower Wind Energy Costs". If you could reference Manitoba Hydro somewhere or provide the link, I think that would be appropriate. Thanks very much for your interest in our research.

Regards,

Dana L. Hoffman, C.E.T.
Emerging Energy Systems
Manitoba Hydro
360 Portage Ave (18th Floor)
Winnipeg, MB
Ph (204)360-4810
danahoffman@hydro.mb.ca

From: Lafreniere.Suzanne@hydro.qc.ca [mailto:Lafreniere.Suzanne@hydro.qc.ca]
Sent: Wednesday, October 20, 2010 11:28 AM
To: Molinski, Tom; Hoffman, Dana
Subject: CIGRE Canada - Request from a student

Dear All:

Please refer to email below.

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CIGRE Canada Coordinator
Hydro-Québec - Groupe Technologie
1500 University St., 4th Floor
Montréal, Québec H3A 3S7
☎ 514 840-3000, ext. 7629
☎ 514 840-5117
✉ lafreniere.suzanne@hydro.qc.ca

De : Shauna McCartney [mailto:[REDACTED]]
Envoyé : samedi 16 octobre 2010 14:39
À : CIGRE Canada
Objet : CIGRE Canada : Email

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Integration of Green and Renewable Energy

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Page 1 of 1

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Modeling of a Variable Speed Wind Turbine with a Permanent Magnet Synchronous Generator

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Thank you,
~Shauna McCartney

Integrated Wind Energy Conversion and Storage System (WECSS)

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Thank you,

-Shauna McCartney

LIST OF REFERENCES

- [1] Janet L. Sawin and Eric Martinot, “Renewables 2010 Global Status Report,” Renewable Energy Policy Network for the 21st Century, Paris, France, 2010.
- [2] Jay Apt and Aimeer Curtright, “The Spectrum of Power from Utility-Scale Wind Farms and Solar Photovoltaic Arrays,” Carnegie Mellon Electricity Industry Center, Pittsburgh, PA, CEIC-08-04, 2008.
- [3] “World Wind Energy Report 2009,” World Wind Energy Association, Bonn Germany, 2010.
- [4] World Wind Energy Association (AWEA). <http://www.wwindea.org> (online May 2010).
- [5] “Windpower Outlook 2009,” American Wind Energy Association, Washington, D.C., 2010.
- [6] “Wind Power Today 2010,” U.S. Department of Energy’s National Renewable Energy Laboratory, Washington D.C., DOE/GO-102010-3011, 2010.
- [7] National Renewable Energy Laboratory. <http://www.nrel.gov/gis/wind.html> (online May 2010).
- [8] AWS Truewind. http://www.nrel.gov/wind/resource_assessment.html (online May 2010).
- [9] American Wind Energy Association. <http://www.awea.org/policy/ptc.html> (online May 2010).
- [10] Patrick Sullivan et al., “Comparative Analysis of Three Proposed Federal Renewable Electricity Standards,” U.S. Department of Energy’s National Renewable Energy Laboratory, Washington D.C., NREL/TP-6A2-45877, 2009.

- [11] Frede Blaabjerg and Zhe Chen, *Power Electronics for Modern Wind Turbines*. San Rafael, CA: Morgan and Claypool, 2006.
- [12] Alejandro Rolan et al., “Modeling of a Variable Speed Wind Turbine with a Permanent Magnet Synchronous Generator”, in *IEEE International Symposium on Industrial Electronics (ESIE 2009)*, Seoul, Korea, 2009, pp. 734-739.
- [13] Ackermann, Thomas, *Wind Power in Power Systems*. West Sussex, England: John Wiley & Sons, 2005, ch. 24.
- [14] *Wind Energy Handbook*, West Sussex, England: John Wiley & Sons, 2001, ch. 3.
- [15] D.L. Hoffman and T.S. Molinski, “How New Technology Developments Will Lower Wind Energy Costs,” in *CIGRE Canada Symposium*. Calgary, Canada, 2009, pp. 1-6.
- [16] Heier, Siegfried, *Grid Integration of Wind Energy Conversion Systems*. West Sussex, England: John Wiley & Sons, 1998, ch. 3.
- [17] Kang Can and Zhang Feng, “Comparison Study of a Vertical-Axis Spiral Rotor and a Conventional Savonius Rotor,” in *Power and Energy Engineering Conf. (APPEEC)*, Singapore, 2010, pp. 1-4.
- [18] M. A. Khan et al., “On Adapting a Small PM Wind Generator for a Multiblade, High Solidity Wind Turbine,” *IEEE Trans. Energy Convers.*, vol. 20, no. 3, pp. 685-692, Sept. 2005.
- [19] Xin-yan Zhang et al., “The Study of on Grid Wind Turbine Generator Made in China,” in *Power and Energy Engineering Conf. (APPEEC)*, Singapore, 2010, pp. 1-4.
- [20] Nicholas P. W. Strachan and Dragan Jovcic, “Improving Wind Power Quality using and Integrated Wind Energy Conversion and Storage System (WECSS)”, in 2008 Power and

- Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, Pittsburg, PA, 2008, pp.1-8.
- [21] Tam Hunt and Sigrid Wright, "A New Energy Direction: A Blueprint for Santa Barbara County," Community Environmental Council, Santa Barbara, CA, 2007.
 - [22] Batarseh, Issa, *Power Electronic Circuits*. Hoboken, NJ: John Wiley & Sons, 2004, ch. 7-9.
 - [23] Cogeneration Technologies. http://www.cogeneration.net/asynchronous_generators.htm (online August 2010).
 - [24] Ali Keyhani et al., *Integration of Green and Renewable Energy in Electric Power Systems*. Hoboken, NJ: John Wiley & Sons, 2010, ch. 4, 8.
 - [25] S. H. Hosseini and E. Babaei, "A New Generalized Direct Matrix Converter," *IEEE Int. Symp. on Industrial Electronics. Proc.*, 2001, Pusan, South Korea, pp. 1071-1076.
 - [26] Poh Chiang Loh et al., "Pulse Width Modulation of Neutral-Point-Clamped Indirect Matrix Converter," *IEEE Trans. on Industry Applications*, vol. 4, no. 6, pp. 1805-1814, 2008.
 - [27] K. Kato and J.-i. Itoh, "Control Strategy for a Buck-Boost Type Direct Interface Converter Using an Indirect Matrix Converter with an Active Snubber," *Applied Power Electronics Conference and Exposition (APEC) 2010*, Fort Worth, TX, pp. 1684-1691.
 - [28] P. K. Ray et al., "Small-Signal Analysis of a Hybrid Distributed Generation System with HVDC-Link and Energy Storage Elements," *Int. Conf. on Emerging Trends in Engineering and Technology (ICETET) 2009*, Nagpoor, India, pp. 1-6.

- [29] G. McNerney and R. Richardson, "The Statistical Smoothing of Power Delivered to Utilities by Multiple Wind Turbines," *IEEE Trans. on Energy Conversion*, vol. 7, no. 4, pp. 644-647, 1992.
- [30] Yaow-Ming Chen and Liu Yuan-Chuan, "Development of Multi-Port Converters for Hybrid Wind-Photovoltaic Power System," *Proc. of IEEE Region 10 Int. Conf. on Electrical and Electronic Technology (TENCON) 2001*, Fukuoka, Japan, pp. 804-808.
- [31] H. S. Ko et al., "A New LMI Representation of LQR Based Voltage Control of Grid-Connected Wind Farm," *Proc. of 2006 American Control Conf.*, Minneapolis, MN, pp. 851-856.
- [32] H. S. Ko et al., "Increase of Fault Ride-Through Capability for the Grid-Connected Wind Farms," *2006 IEEE Power Engineering Society General Meeting*, Montreal, Quebec, pp. 1-6.
- [33] Zhongming Ye et al., "Circulating Current Minimization in High-Frequency AC Power Distribution Architecture with Multiple Inverter Modules Operated in Parallel," *IEEE Trans. on Industrial Electronics*, vol. 54, no. 5, pp. 2673-2687, 2007.
- [34] R. Fadaeinedjad et al., "Flicker Contribution of a Wind Power Plant with Single and Multiple Turbine Representations," *IEEE Canada Electrical Power Conference (EPC) 2007*, Montreal, Quebec, pp. 1-6.
- [35] E. Muljadi et al., "Method of Equivalencing for a Large Wind Power Plant with Multiple Turbine Representation," *2008 IEEE Power and Energy Society General Meeting*, Pittsburgh, PA, pp. 1-9.

- [36] O. Anaya-Lara et al., "Transient Analysis of DFIG Wind Turbines in Multi-Machine Networks," *2005 Int. Conf. and Expo. on Electricity Distribution (CIRED)*, Turin, Italy, pp. 1-5.
- [37] Interconnecting Distributed Resources with Electric Power Systems, IEEE Standard 1547, 2008.
- [38] Standard for Wind Turbine Generator Systems, IEC Standard 61400, 2010.
- [39] X. Li and A. Bhat, "Multi-Cell Operation of a High-Frequency Isolated DC/AC Converter for Grid-Connected Wind Generation Applications," *2009 Int. Conf. on Industrial and Information Systems (ICIIS)*, Peradeniya, Sri Lanka, pp. 169-174.
- [40] J. D. Clark and B. H. Stark, "Component Sizing for Multi-Source Renewable Energy Systems," *2009 IEEE Int. Conf. on Industrial Informatics*, Cardiff, UK, pp. 89-94.
- [41] MATLAB SimPowerSystems for Use with Simulink User's Guide, Version 4.1.1, <http://www.MathWorks.com/>.